AD-A040 071 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 4/2

ON ONE DIMENSIONAL GEOSTROPHIC ADJUSTMENT WITH FINITE DIFFERENC--ETC(U)

APR 77 A L SCHOENSTADT

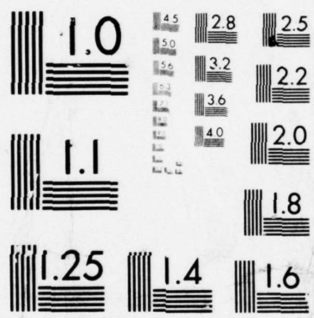
UNCLASSIFIED NPS-53ZH77041 NL

| OF |

AD
A040071

END

DATE
FILMED
6-77



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

NPS-53Zh77041

NAVAL POSTGRADUATE SCHOOL

Monterey, California

ON ONE DIMENSIONAL GEOSTROPHIC ADJUSTMENT WITH FINITE DIFFERENCING

by

Arthur L. Schoenstadt

April 1977

Approved for public release; distribution unlimited

Prepared for:
Naval Environmental Prediction Research Facility, Monterey, CA 93940

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral Isham W. Linder
Superintendent

Jack R. Borsting
Provost

The work reported herein was supported by the Naval Environmental Prediction Research Facility, Monterey, California.

Reproduction of all or part of this report is authorized.

This report was prepared by:

ARTHUR L. SCHOENSTADT
Assistant Professor of Mathematics

Reviewed by:

CARROLL O. WILDE, Chairman
Department of Mathematics

Released by:

ROBERT R. FOSSUM
Dean of Research

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: (14) NPS-53Zh77041	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) On One Dimensional Geostrophic Adjustment with Finite Differencing.		5. TYPE OF REPORT & PERIOD COVERED: (9) Interim rept. for period ending Jan 1977,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Arthur L. Schoenstadt		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Postgraduate School, Monterey, CA 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Environmental Prediction Research Facility, Monterey, CA 93940		12. REPORT DATE: (11) Apr 1977
		13. NUMBER OF PAGES: ~~20~~ (12) 15p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16 DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19 KEY WORDS (Continue on reverse side if necessary and identify by block number)

Finite Differences
Geostrophic Adjustment
Numerical Weather Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A result of Winninghoff (1968) on the effect of finite differencing in the process of geostrophic adjustment in one dimension is shown to be erroneous. The correct result is provided, and Winninghoff's conclusions reexamined.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 450 - mb

Winninghoff [6], in his doctoral thesis investigated the effect on the process of geostrophic adjustment [2] in one dimension of several different spatial discretization schemes. His results were later incorporated by Arakawa and Lamb [1]. The model he chose, which had been previously investigated by Rossby [4], Cahn [3] and others, was the linearized one-dimensional shallow water equations with no mean flow, in an infinite region:

$$\frac{\partial u}{\partial t} - fv + g\frac{\partial h}{\partial x} = 0 \tag{1}$$

$$\frac{\partial v}{\partial t} + fu = 0 \tag{2}$$

$$\frac{\partial h}{\partial t} + H\frac{\partial u}{\partial x} = 0 \, , \tag{3}$$

where u is the perturbation velocity in the x direction, v is the perturbation velocity normal to the x direction, H and h are the mean and perturbed heights of the free surface, respectively, and $g > 0$ and $f > 0$ are gravitational and Coriolis parameters, respectively. The purpose of this note is to point out certain errors in Winninghoff's solutions, present the correct solutions, and reexamine his conclusions in light of the correct solutions.

Winninghoff followed earlier studies in solving (1)-(3) by eliminating between the equations to arrive at:

$$\frac{\partial^2 u}{\partial t^2} + f^2 u - gH\frac{\partial^2 u}{\partial x^2} = 0 \, , \tag{4}$$

then solving (4) by a Fourier Transform approach. After solving (4), solutions for h and v are obtained by substitution into (2) and (3), although closed-form solutions are not presented in some of the papers. Note the dispersive character of (4) is clearly seen by assuming a wave solution:

$$u(x,t) = A\, e^{i(kx-vt)}$$

which implies:

$$v^2 = f^2 + gHk^2 = f^2\,(1 + \lambda^2 k^2),\ \lambda = \sqrt{gH/f}\ . \tag{5}$$

In [5], we presented a method where (1)-(3) were transformed directly, then the transformed problem was solved as a system of coupled ordinary differential equations.[1] If we denote transforms by an overhead tilde, e.g.

$$\tilde{u}(k,t) = \int_{-\infty}^{\infty} u(x,t) e^{-ikx}\, dx\ ,$$

then (1)-(3) reduce to

$$\begin{aligned} \frac{d\tilde{u}}{dt} &= f\tilde{v} - ikg\,\tilde{h} \\ \frac{d\tilde{v}}{dt} &= -f\tilde{u} \\ \frac{d\tilde{h}}{dt} &= -ikH\,\tilde{u}\ . \end{aligned} \tag{6}$$

Now, if we denote initial values by a subscript, e.g.

$$\tilde{u}_0(k) = \int_{-\infty}^{\infty} \tilde{u}(x,0) e^{-ikx}\, dx = \tilde{u}(k,0)\ ,$$

and use Winninghoff's initial conditions:

$$\begin{aligned} u(x,0) &= 0 \\ h(x,0) &= 0 \\ v(x,0) &= \begin{cases} V_0, & -a < x < a \\ 0, & \text{otherwise}\ , \end{cases} \end{aligned} \tag{7}$$

then using equation (12) of [5], the transformed solution is:

$$\tilde{u}(k,t) = \frac{2fV_0}{\nu} \sin(\nu t) \frac{\sin(ak)}{k}$$

$$\tilde{v}(k,t) = 2V_0 \left\{ \frac{k^2 gH}{\nu^2} + \frac{f^2}{\nu^2} \cos(\nu t) \right\} \frac{\sin(ak)}{k} \tag{8}$$

$$\tilde{h}(k,t) = -\frac{2ikHfV_0}{\nu^2} \{1 - \cos(\nu t)\} \frac{\sin(ak)}{k} \ .$$

Winninghoff, using elimination, solved only for $u(x,t)$,

$$\begin{aligned} u(x,t) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{u}(k,t) e^{ikx}\, dk \\ &= \frac{2faV_0}{\pi} \int_0^{\infty} \frac{\sin(ak)}{ak} \frac{\sin(\nu t)}{\nu} \cos kx\, dk \ , \end{aligned} \tag{9}$$

then solved for $h(x,t)$ using the continuity equation. [If this is done to (9), or if the third equation in (8) is inverted directly, we find

$$h(x,t) = \frac{2HfV_0}{\pi} \int_0^{\infty} \frac{\{1 - \cos(\nu t)\}}{\nu^2} \sin(ak) \sin(kx) dk \ . \tag{10}$$]

The error in his solution occurs in converting from the differential case to the discretized case, using any one of the difference schemes he denotes as schemes A-E. (Figure 1) He performs this conversion by simply replacing ν in (9) by its equivalent finite difference form, evaluating the integral numerically, then finding $h(x,t)$ from the continuity equation. We now show this approach neglects the effects of spatial averaging of $u(x,t)$ and $v(x,t)$ that occurs in Schemes C and D. For example, in Scheme C, the finite difference form of (1)-(3) is:

$$\left.\begin{aligned} \frac{\partial u}{\partial t} &= f \frac{[v(x+d/2,t) + v(x-d/2,t)]}{2} - g \frac{[h(x+d/2,t) - h(x-d/2,t)]}{d} \\ \frac{\partial v}{\partial t} &= -f \frac{[u(x+d/2,t) + u(x-d/2,t)]}{2} \\ \frac{\partial h}{\partial t} &= -H \frac{[u(x+d/2,t) - u(x-d/2,t)]}{d} \ . \end{aligned}\right\} \tag{11}$$

If we transform this system, distinguishing from the differential system by using a subscript c on the variables, we have:

$$\begin{aligned}
\frac{d\tilde{u}_c}{dt} &= f\cos(kd/2)\tilde{v}_c - ig\,\frac{\sin(kd/2)}{(d/2)}\,\tilde{h}_c \\
\frac{d\tilde{v}_c}{dt} &= -f\cos(kd/2)\tilde{u}_c \qquad\qquad (12) \\
\frac{\partial\tilde{h}_c}{dt} &= -iH\,\frac{\sin(kd/2)}{(d/2)}\,\tilde{u}_c \quad .
\end{aligned}$$

This system is identical to (6), except that f is replaced by $f\cos(kd/2)$ and k is replaced by $\sin(kd/2)/(d/2)$. Thus the solutions for $u_c(x,t)$ and $h_c(x,t)$, corresponding to Arakawa's initial condition, can be obtained by making a similar replacement in (12) of [5], to yield:

$$u_c(x,t) = \frac{2faV_0}{\pi}\int_0^\infty \frac{\sin(ak)}{ak}\,\frac{\sin(\nu_c t)}{\nu_c}\cos(kx)\cos(kd/2)dk\ , \qquad (13)$$

$$h_c(t) = \frac{2HfaV_0}{\pi}\int_0^\infty \frac{\{1-\cos(\nu_c t)\}}{\nu_c^2}\,\frac{\sin(ak)}{ak}\sin(kx)\,\frac{\sin(kd/2)\cos(kd/2)}{(d/2)}dk\ , \qquad (14)$$

where

$$\nu_c^2 = f^2(1 + 4(\lambda/d)^2\sin^2(kd/2))\ . \qquad (15)$$

Observe that (13) is not obtainable from (9) simply by replacing ν by ν_c . This is because of the $\cos(kd/2)$ term that arises from the spatial averaging of v and u that occurs in the first and second equations of (11), respectively. Repeating these calculations for the other schemes will show that $u(x,t)$ in Scheme D also requires a $\cos(kd/2)$ term, and that $h(x,t)$ is given, in general, by

$$h(x,t) = \frac{2HfaV_0}{\pi}\int_0^\infty D(k)\,\frac{\{1-\cos\nu t\}}{\nu^2}\,\frac{\sin(ak)}{ak}\sin(kx)dk \qquad (16)$$

where

$$D(k) = \begin{cases} k & , \text{ Differential} \\ \dfrac{\sin(kd)}{d} & , \text{ Scheme A} \\ \dfrac{\sin(kd/2)}{(d/2)} & , \text{ Scheme B} \\ \dfrac{\cos(kd/2)\sin(kd/2)}{(d/2)} & , \text{ Scheme C} \\ \dfrac{\cos^2(kd/2)\sin(kd/2)}{(d/2)} & , \text{ Scheme D} \\ \dfrac{\sin(kd/\sqrt{2})}{(d/\sqrt{2})} & , \text{ Scheme E} \end{cases} \tag{17}$$

and

$$\nu/f = \begin{cases} [1 + \lambda^2 k^2]^{1/2} & , \text{ Differential} \\ [1 + (\lambda/d)^2 \sin^2 (kd)]^{1/2} & , \text{ Scheme A} \\ [1 + 4(\lambda/d)^2 \sin^2 (kd/2)]^{1/2} & , \text{ Scheme B} \\ [\cos^2 (kd/2) + 4(\lambda/d)^2 \sin^2 (kd/2)]^{1/2} & , \text{ Scheme C} \\ [\cos^2 (kd/2) + (\lambda/d)^2 \sin^2 (kd)]^{1/2} & , \text{ Scheme D} \\ [1 + 2(\lambda/d)^2 \sin^2 (kd/\sqrt{2})]^{1/2} & , \text{ Scheme E} \end{cases} \tag{18}$$

In Figure 2, the integrals given by (16) are used to compute (h/H) at $t = 80$ hours in the same manner as done by Winninghoff, i.e., using Simpson's rule with 600 subintervals in the interval $(0,\pi/d)$. The relevant parameter values used were

$$f = 10^{-4} \text{ sec}^{-1}$$

$$g = 10 \text{ m sec}^{-2}$$

$$H = 10^3 \text{ m}$$

$$a = d = \lambda/2 .$$

These graphs too should be compared to Figure 3, which shows the equivalent evaluation of (10), with only $\nu(k)$ replaced by its equivalent finite difference value. (Figure 3 appears identical to Figure 3.6 in Winninghoff.) Note especially the effect on the solution to Scheme D. We conclude that Winninghoff obtained such ill-behaved solutions in this case because he neglected the $\cos(kd/2)$ term in the numerator of $u(x,t)$ in these cases, and this term helps to control the singular behavior of $[\nu(k)]^{-1}$ as $k \to \pi$ in Scheme D.

Winninghoff eliminated Scheme D from further study due to the extremely noisy behavior shown by Figure 3. Since his calculation was erroneous, it can not be discarded for this reason, however, as he showed, it is still seriously deficient in terms of phase speed errors, and should probably be discarded for this reason.

Acknowledgement

This work was supported by the Naval Environmental Prediction Facility, Monterey, CA 93940

FOOTNOTE

1. A sgn term was erroneously omitted from certain expressions in [5]. Thus, in [5], equation (13) should read,

$$h_S(x) = h(x,0) - \frac{H}{2\lambda^2 f} \int_{-\infty}^{\infty} \operatorname{sgn}(x - s)e^{-|x - s|/\lambda}\{\frac{g}{f}\frac{\partial h}{\partial x}(s,0) - v(s,0)\}ds ,$$

the equation immediately above (28) should read

$$\frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{i\sigma}{1 + \lambda^2\sigma^2} e^{ikx} dk = - \frac{\Delta x \, e^{-\beta|x|\lambda}\operatorname{sgn}(x)}{\lambda[\lambda^2 + (\Delta x)^2]^{1/2}} \sum_{n=-\infty}^{\infty} \delta(x - (2n - 1)\Delta x) ,$$

equation (30) should read

$$h_S(x,0) = h(x,0) + \frac{H}{2\lambda f[\lambda^2 + (\Delta x^2)]^{1/2}}$$

$$\times \sum_{n=-\infty}^{\infty} \{\operatorname{sgn}((2n - 1)\Delta x)e^{-\beta|(2n - 1)\Delta x|/\lambda} \hat{d}(x - (2n - 1)\Delta x,0)(2\Delta x)\} ,$$

and equation (2.8) should be identical to the second equation in this note.

LIST OF FIGURES

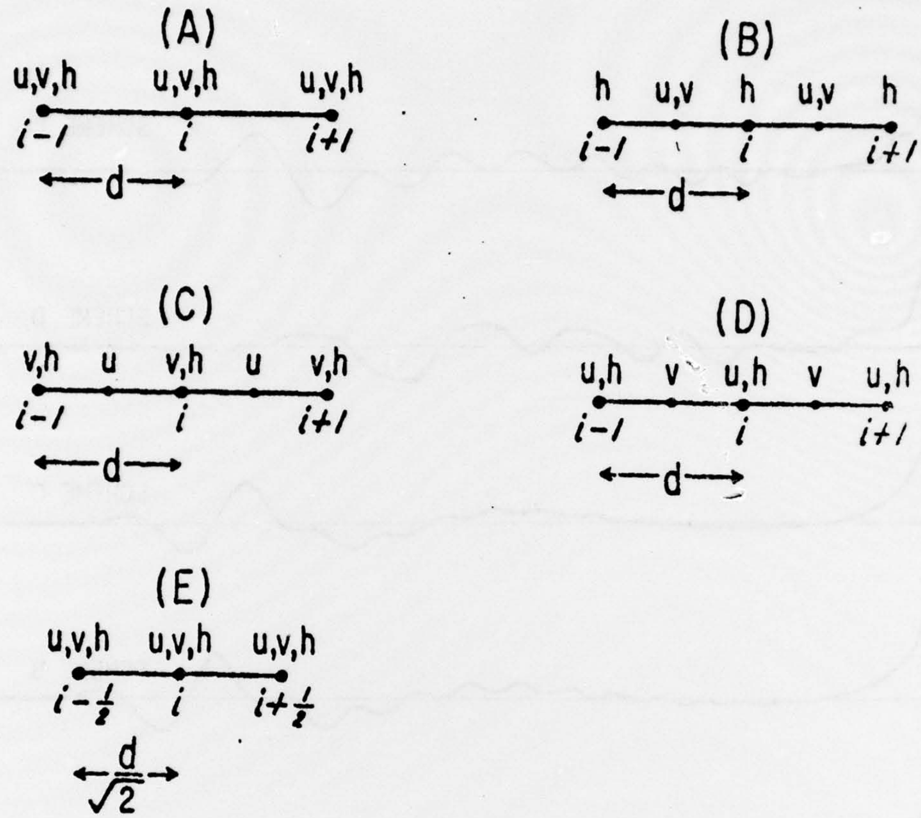
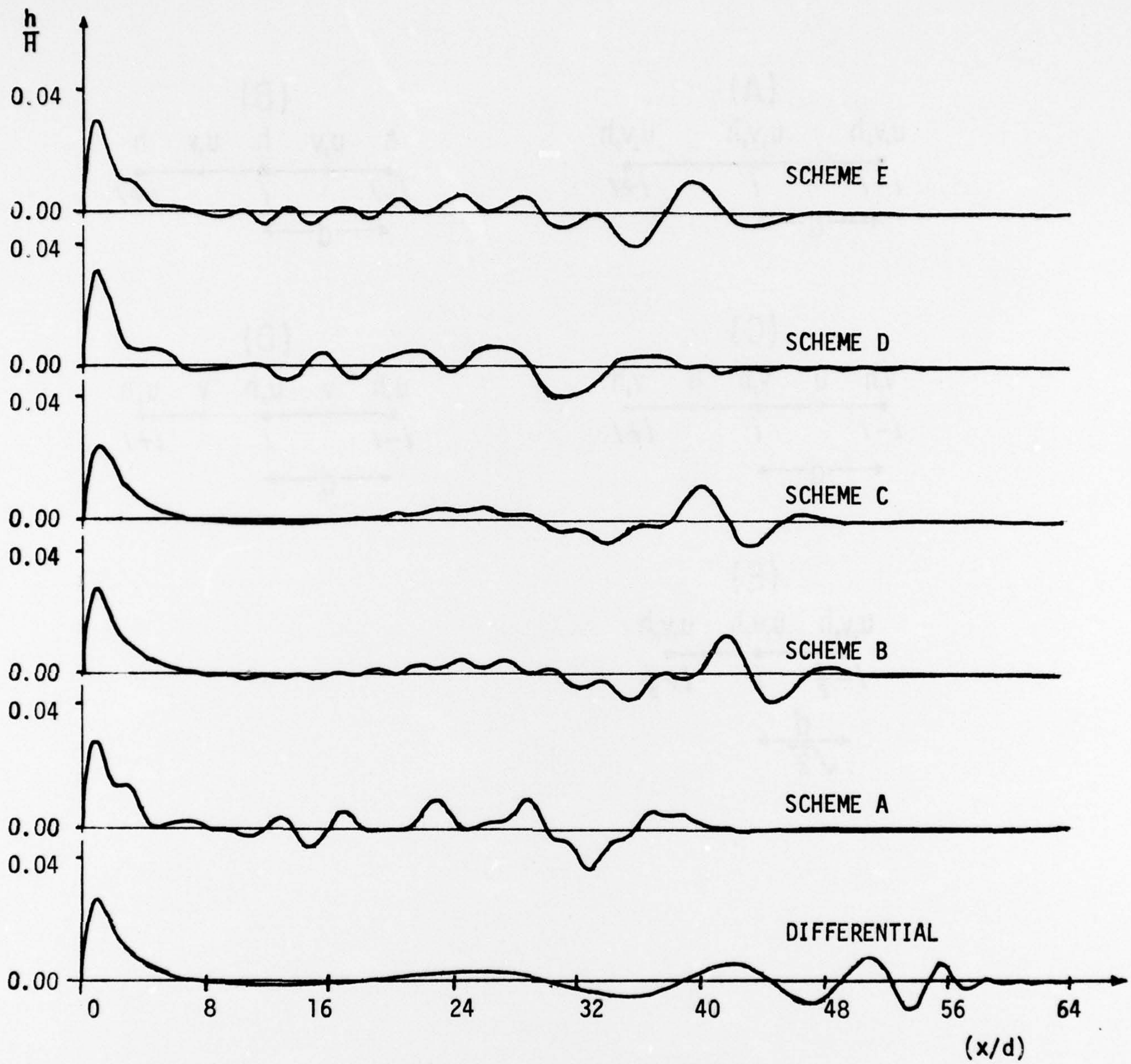

(A)
u,v,h
u,v,h
u,v,h
i-1
i
i+1
d
(B)
h
u,v
h
u,v
h
i-1
i
i+1
d
(C)
v,h
u
v,h
u
v,h
i-1
i
i+1
d
(D)
u,h
v
u,h
v
u,h
i-1
i
i+1
d
(E)
u,v,h
u,v,h
u,v,h
i-½
i
i+½
d/√2

Figure 1



h/H
0.04
0.00
SCHEME E
SCHEME D
SCHEME C
SCHEME B
SCHEME A
DIFFERENTIAL
0
8
16
24
32
40
48
56
64
(x/d)

Figure 2

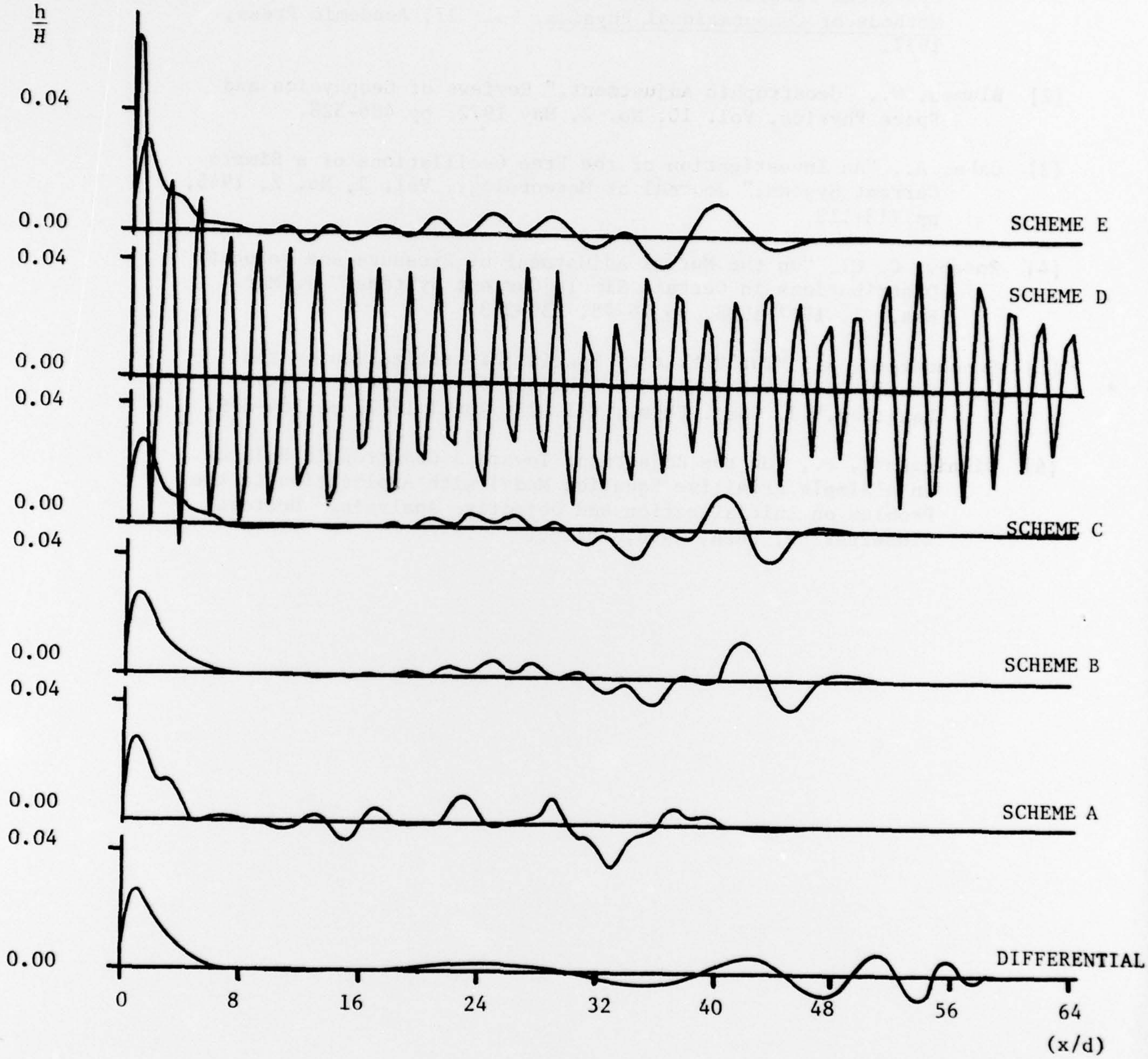

h/H
0.04
0.00
SCHEME E
0.04
SCHEME D
0.00
0.04
0.00
SCHEME C
0.04
0.00
SCHEME B
0.04
0.00
SCHEME A
0.04
0.00
DIFFERENTIAL
0
8
16
24
32
40
48
56
64
(x/d)

Figure 3

References

[1] Arakawa, A. and Lamb, V. R., "Computational Design of the Basic Dynamical Processes of the UCLA General Circulation Model", Methods of Computational Physics, Vol. 17, Academic Press, 1977.

[2] Blumen, W., "Geostrophic Adjustment," Reviews of Geophysics and Space Physics, Vol. 10, No. 2, May 1972, pp 485-528.

[3] Cahn, A., "An Investigation of the Free Oscillations of a Simple Current System," Journal of Meteorology, Vol. 2, No. 2, 1945, pp 113-119.

[4] Rossby, C. G., "On the Mutual Adjustment of Pressure and Velocity Distributions in Certain Simple Current Systems," J. Mar. Res., 1, 1937-1938, pp 15-28, 239-263.

[5] Schoenstadt, A., "The Effect of Spatial Discretization on the Steady-State and Transient Behavior of a Dispersive Wave Equation," J. Comp. Phys., Vol. 23, April 1977, pp 364-379.

[6] Winninghoff, F., "On the Adjustment Toward a Geostrophic Balance in a Simple Primitive Equation Model with Application to the Problem on Initialization and Objective Analysis," Doctoral Dissertation, UCLA, 1968, 161 pp.

DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Dr. A. L. Schoenstadt, Code 53Zh Department of Mathematics Naval Postgraduate School Monterey, CA 93940	10
4.	Dr. R. T. Williams, Code 51Wu Department of Meteorology Naval Postgraduate School Monterey, California 93940	1
5.	Commanding Officer Naval Weather Service Command Headquarters 3101 Building 200 Washington Navy Yard Washington, D. C. 20374	1
6.	Officer in Charge Environmental Prediction Research Facility Naval Postgraduate School Monterey, California 93940	10
7.	Dean of Research Naval Postgraduate School Monterey, California 93940	2
8.	Commanding Officer Fleet Numerical Weather Central Naval Postgraduate School Monterey, California 93940	2
9.	Naval Oceanographic Office Library (Code 3330) Washington, D. C. 20373	1
10.	AFCRL - Research Library L. G. Hanscom Field ATTN: Nancy Davis/Stop 29 Bedford, Massachusetts 01730	1

11. Commander, Air Weather Service 1
Military Airlift Command
United States Air Force
Scott Air Force Base, Illinois 62226

12. Dr. R. Alexander 1
The RAND Corporation
1700 Main Street
Santa Monica, California 90406

13. Dr. A. Arakawa 1
Department of Meteorology
University of California
Los Angeles, California 90024

14. Dr. D. Archer 1
Mathematics Department
University of North Carolina
UNCC Station
Charlotte, North Carolina 28223

15. Atmospheric Sciences Library 1
National Oceanic and Atmospheric Administration
Silver Spring, Maryland 20910

16. Mr. E. Barker 1
Environmental Prediction Research Facility
Naval Postgraduate School
Monterey, California 93940

17. Dr. W. Blumen 1
Department of Astro-Geophysics
University of Colorado
Boulder, Colorado 80302

18. Dr. F. P. Bretherton 1
National Center for Atmospheric Research
P. O. Box 3000
Boulder, Colorado 80303

19. Dr. John Brown 1
National Meteorological Center/NOAA
World Weather Building
Washington, D. C. 20233

20. Dr. C. P. Chang, Code 51Cj 1
Department of Meteorology
Naval Postgraduate School
Monterey, California 93940

21. Professor J. G. Charney 1
54-1424
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

22. Dr. C. Comstock, Code 53Cs 1
Department of Mathematics
Naval Postgraduate School
Monterey, California 93940

23. Dr. D. Dietrick 1
JAYCOR
205 S. Whiting St., Suite 409
Alexandria, Virginia 22304

24. Dr. R. L. Elsberry, Code 51Es 1
Department of Meteorology
Naval Postgraduate School
Monterey, California 93940

25. Dr. Frank D. Faulkner, Code 53Fa 1
Mathematics Department
Naval Postgraduate School
Monterey, California 93940

26. Dr. Richard Franke, Code 53Fe 1
Department of Mathematics
Naval Postgraduate School
Monterey, California 93940

27. Dr. J. A. Galt 1
NOAA - Pac. Mar. Envir. Lab.
University of Washington WB-10
Seattle, Washington 98105

28. Dr. W. L. Gates 1
The RAND Corporation
1700 Main Street
Santa Monica, California 90406

29. Dr. G. J. Haltiner, Code 51Ha 1
Chairman, Department of Meteorology
Naval Postgraduate School
Monterey, California 93940

30. Dr. R. L. Haney, Code 51Hy 1
Department of Meteorology
Naval Postgraduate School
Monterey, California 93940

31. LT Donald Hinsman 1
Fleet Numerical Weather Central
Naval Postgraduate School
Monterey, California 93940

32. Dr. J. Holton 1
Department of Atmospheric Sciences
University of Washington
Seattle, Washington 98105

33. Dr. B. J. Hoskins 1
Department of Geophysics
University of Reading
Reading
United Kingdom

34. Dr. D. Houghton 1
Department of Meteorology
University of Wisconsin
Madison, Wisconsin 53706

35. Dr. A. Kasahara 1
National Center for Atmospheric Research
P. O. Box 3000
Boulder, Colorado 80303

36. Dr. L. D. Kovach, Code 53Kv 1
Chairman, Department of Mathematics
Naval Postgraduate School
Monterey, California 93940

37. Dr. C. E. Leith 1
National Center for Atmospheric Research
P. O. Box 3000
Boulder, Colorado 80303

38. Dr. J. M. Lewis 1
Laboratory for Atmospheric Research
University of Illinois
Urbana, Illinois 61801

39. Dr. E. N. Lorenz 1
Department of Meteorology
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

40. Dr. R. Madala 1
Code 7750
Naval Research Laboratory
Washington, D. C. 20390

41. Dr. J. D. Mahlman 1
Geophysical Fluid Dynamics Laboratory
Princeton University
Princeton, New Jersey 08540

42. Dr. G. Morris, Code 53Mj 1
Department of Mathematics
Naval Postgraduate School
Monterey, California 93940

43. Meteorology Library (Code 51) 1
Naval Postgraduate School
Monterey, California 93940

44. LT W. F. Mihok 1
Fleet Numerical Weather Central
Naval Postgraduate School
Monterey, California 93940

45. National Center for Atmospheric Research 1
Box 1470
Boulder, Colorado 80302

46. Director, Naval Research Laboratory 1
ATTN: Technical Services Information Center
Washington, D. C. 20390

47. Department of Oceanography, Code 58 1
Naval Postgraduate School
Monterey, California 93940

48. Office of Naval Research 1
Department of the Navy
Washington, D. C. 20360

49. Dr. T. Ogura 1
Laboratory for Atmospheric Research
University of Illinois
Urbana, Illinois 61801

50. Professor N. A. Phillips 1
National Meteorologican Center/NOAA
World Weather Building
Washington, D. C. 20233

51. Dr. S. Piacsek 1
Code 7750
Naval Research Laboratory
Washington, D. C. 20390

52.	Dr. T. Rosmond Environmental Prediction Research Facility Naval Postgraduate School Monterey, California 93940	1
53.	Dr. Y. Sasaki Department of Meteorology University of Oklahoma Norman, Oklahoma 73069	1
54.	Dr. Fred Shuman, Director National Meteorological Center World Weather Building Washington, D. C. 20233	1
55.	Dr. R. Somerville NCAR P. O. Box 3000 Boulder, Colorado 80303	1
56.	Dr. D. Williamson National Center for Atmospheric Research P. O. Box 3000 Boulder, Colorado 80303	1
57.	Dr. F. J. Winninghoff 1085 Steeles Avenue, #503 Willowdale (Toronto) Ontario M2R2T1 Canada	1
58.	Dr. M. G. Wurtele Department of Meteorology University of California Los Angeles, California 90024	1
59.	Dr. J. Young Department of Meteorology University of Wisconsin Madison, Wisconsin 53706	1
60.	Hugh W. Ellsaesser Lawrence Livermore Laboratory P.O. Box 808 Livermore, CA 94550	1
61.	Mei-Kao Liu System Applicaitons, Inc. 950 Northgate Drive San Rafael, CA 94903	1